

# La logistique des patients aux hôpitaux

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# Logistique de la santé

- Logistique classique: médicaments, fournitures, linge, ...
- Logistique des patients: processus principales de l'hôpital
  - Service: patient = client fait parti du processus
  - Entente générale: La domaine de la santé se compare à la fabrication des années 70
  - Donc beaucoup à gagner!

# La politique aux Pays-Bas

- Les grand chefs d'entreprise ont donnés leur avis à la demande du ministre de la santé
- Bakker (pdg de TNT): réduction de coût de 3.5 Milliards d'Euro est possible
  - Si la France était comparable (4 fois la population des P-B): 14 Milliards d'Euro
- Maintenant: plusieurs programmes initiés et payés par le ministère



# La base: “advanced access”

- Notions clés:
  - Repenser les processus pour les rendre stable
  - Effort supplémentaire pour enlever la file d’attente
  - Soutien de tout le département inclusif les médecins
  - Surtout appliqué aux polycliniques
- Mayo Clinics (USA), IHI
- Processus relativement simple

The image shows the top section of the IHI.org website. On the left, the logo 'IHI.org' is displayed in white on a black background. To its right, the text 'A resource from the Institute for Healthcare Improvement' is written in white. Further right, there are three links: 'Log In/Register', 'Contact Us', and 'Site Map'. On the far right, there is a search bar with the word 'Search' above it and a search button. Below the search bar, the text 'More Search Options' is visible. The main banner features a photograph of several healthcare professionals in a clinical setting. Overlaid on the banner is the text: 'We invite you to be a part of a global community dedicated to improving health care for all patients.'



# La mode: lean Six Sigma

- Concept du “hidden factory”
- Champion vs. Black/green belt
- Aspect statistique pratiquement perdu en santé (et surtout pas  $6\sigma$ ...)
  - Lié aux caractéristiques de la santé

# Caractéristique 1: financement pervers

- Payé pour une quantité fixe, même s'il y a de la demande en plus
  - Trop de traitements: pas payé
  - Pas assez de traitements: moins payé
- Avant: pas de limite au financement

# Caractéristique 2: organisation

- “bureaucratie professionnelle”
- Approche par spécialisme et pas par groupe de patients
- Changements à cause des contraintes financières actuelles (grandes opportunités pour la R.O.)

# Caractéristique 3: diversité des patients

- Médecins: chaque patient est unique
  - Groupe des patients homogènes
  - Reste hétérogène
- A la mode (avant lean 6 $\sigma$ ): focused factories
  - pour les groupes homogènes
  - Par exemple: Cataracte, cancer du sein, ...
  - Mais le reste???

# Caractéristique 4: l'aléa

- Temps de traitements, parcours des patients imprévisibles
- Extern/inévitable vs. Intern/évitable
  - Urgences selon processus de Poisson; traitements planifiés aussi aléatoires!
  - Retard des opérations: complications pendant l'opération mais aussi bien les bouchons du matin (et est-ce que les infections sont-elles vraiment externes?)

# Classification des problèmes

- Qualité de service vs. coût
- Long terme: la capacité (ressource) à mettre en œuvre
- Court terme: utilisation de cette ressource
- Contraintes médicales

# Systemes de base

- Serveur unique, patients consecutives (policlinique)
- Dimensionnement et allocation de ressources des serveurs paralleles (unite de soin)
- Ressource partagee (MRI, bloc operatoire)
- Prise de ressources simultane (salle d'operation + lit aux SI, one-stop shop dans une policlinique)
- Chaîne de ressources (SI puis unite de soin)

# Système de base 1: Serveur unique, patients consecutives

- Appointment scheduling in medical practices
- Theoretical interest:
  - From queueing perspective interesting arrival process
- Practical interests:
  - Individual scheduling standard
  - Implies “late start” and tardiness
  - Room for improvement

# State of the art

- Bailey Welch: individual with last patient in front
- Vanden Bosche & Dietz: series of papers with submodularity as technique

# Our contribution

- Anke Hutzschenreuter: simulations under practical conditions (no-shows, delays, multiple types of patients)
- Parijat Dube, Dieter Fiems, Philippe Nain: calculations for steady state  $D + \text{delay} | G | 1$  queue
- Guido Kaandorp: optimization using (with hindsight) similar techniques as Vd Bosche & Dietz (HCMS 2007)

Goal :“Optimize” appointment schedule

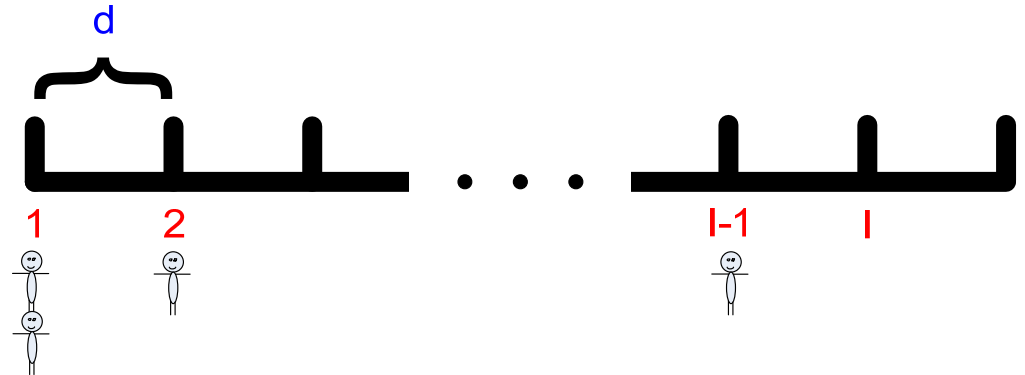
Objective: Minimize weighted sum of...

**Mean idle time doctor**

**& Mean waiting time patients**



# Model



- Variables:
  - $I$ : # intervals
  - $d$ : length interval
  - $n$ : total # patients
  - $\beta$ : average service time
- Decision variables:
  - $x_t$ : # of patients scheduled at time  $t$

# Optimization method

- Local search: shift one or more patients
- Central question: how to choose neighborhood?
- Result: for a good choice of neighborhood convergence to optimal schedule
- Proof by multimodularity (extension of convexity to grid)

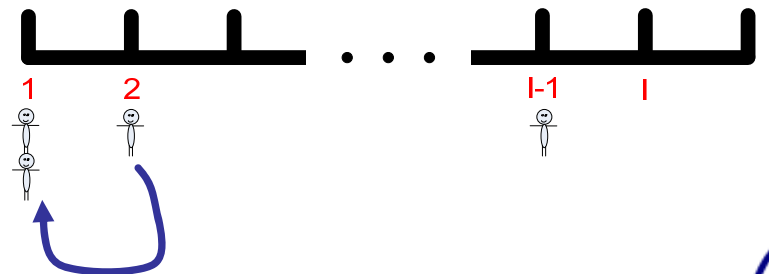
# Neighborhood

- All permutation of these vectors:

$$\mathcal{V}^* = \left\{ \begin{array}{c} u_1, \\ u_2, \\ u_3, \\ \vdots \\ u_{I-1}, \\ u_I \end{array} \right\} = \left\{ \begin{array}{c} (-1, 0, \dots, 0, 1), \\ (1, -1, 0, \dots, 0), \\ (0, 1, -1, 0, \dots, 0), \\ \vdots \\ (0, \dots, 1, -1, 0), \\ (0, \dots, 0, 1, -1) \end{array} \right\}$$

- all combination of 1-interval shifts starting from  $x$

$$x + v_1 + \dots + v_k \text{ with } \{v_1, \dots, v_k \subset \mathcal{V}^*\}$$



# Internet tool

**Optimal outpatient appointment scheduling tool**

|                          |                                 |         |
|--------------------------|---------------------------------|---------|
| Average service time     | <input type="text" value="25"/> | minutes |
| Number of intervals      | <input type="text" value="10"/> |         |
| Length of interval       | <input type="text" value="30"/> | minutes |
| Total number of arrivals | <input type="text" value="10"/> |         |
| Percentage no-shows      | <input type="text" value="5"/>  | %       |
| alpha waiting            | <input type="text" value="3"/>  |         |
| alpha idle time          | <input type="text" value="1"/>  |         |
| alpha tardiness          | <input type="text" value="1"/>  |         |

Press the button to

**DEMO**

# Current work

- Simplification online tool
- Multiple types of patients
- Inclusion emergency
- Application to other scheduling problems (e.g., MRI slot assignment, systèmes de base 3)
- Joint work with Paulien Out

# Systeme de base 2: Dimensionnement et allocation de ressources des serveurs paralleles

- Standard ward occupancy: 85%
- However: rejection % varies
- Society: costs *and* service level increasingly important
- Reasons to revisit the utilization requirement



# First ideas

- Beds = servers
- LoS (“length of stay”) = service times
- Arrivals are  $\approx$  Poisson (?)
- Patients that find all beds occupied are rejected

This is the Erlang B =  $M|M|s|s$  model

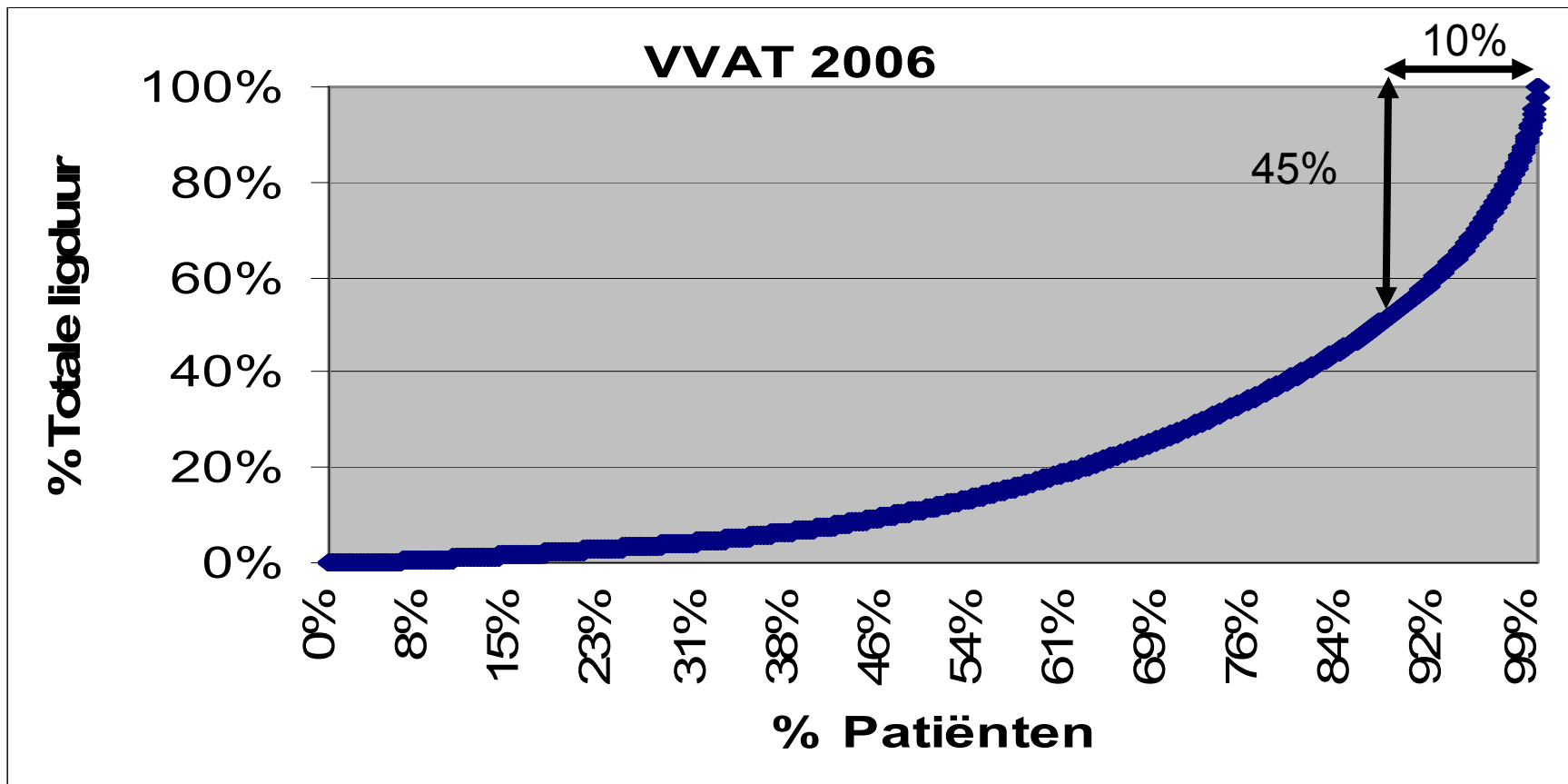
# Erlang B and Excel

- Excel func Poisson(X, Mean, Cumulative)
- Load = Av arrivals p day \* Av LoS
- Rejected prob =  
Poisson(No Beds, Load, False) /  
Poisson(No Beds, Load, True)
- Utilization = Load \* (1 – rej. prob) / No Beds
- Demo

# Employment in VUmc

- Internship Lilian v Zanten
- Supervisors:
  - René Bekker (Faculty of Sciences VU)
  - Arnoud de Bruin (staff advisor VUmc)

# Data analysis: LoS

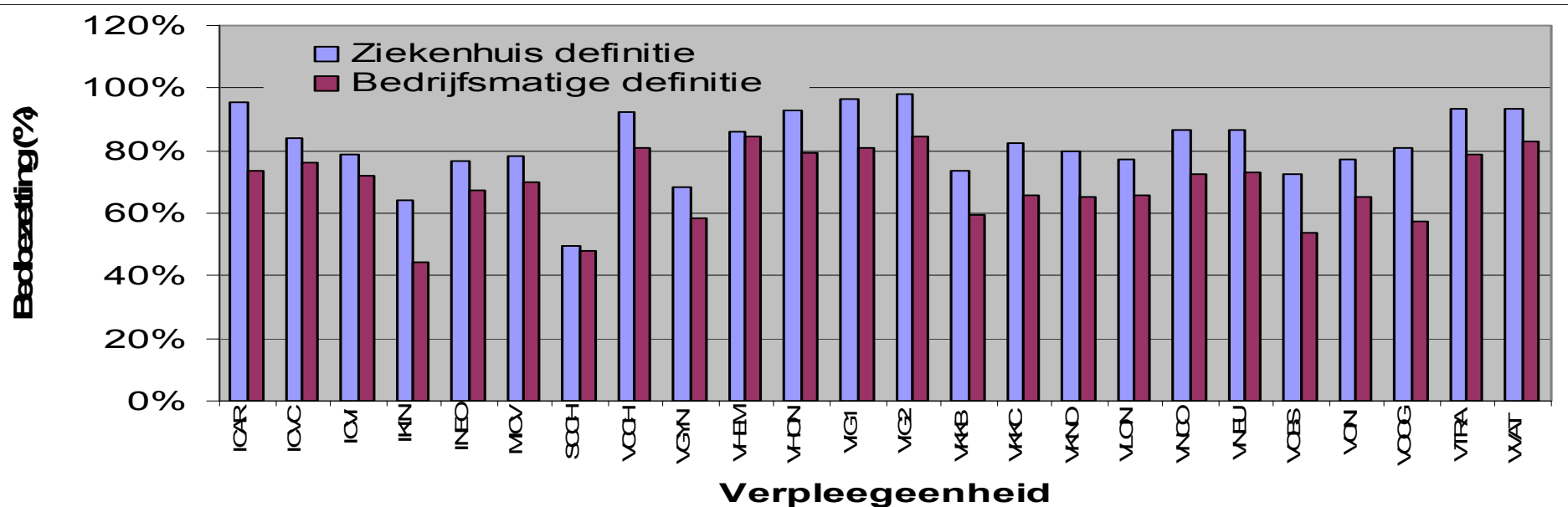


# Variability of LoS

- Well known: Erlang B insensitive to LoS distribution, only ALoS matters
- But: Heavy tail = “deep” Lorenz curve → ALoS can be reduced significantly by reducing LoS of a small group

# But...

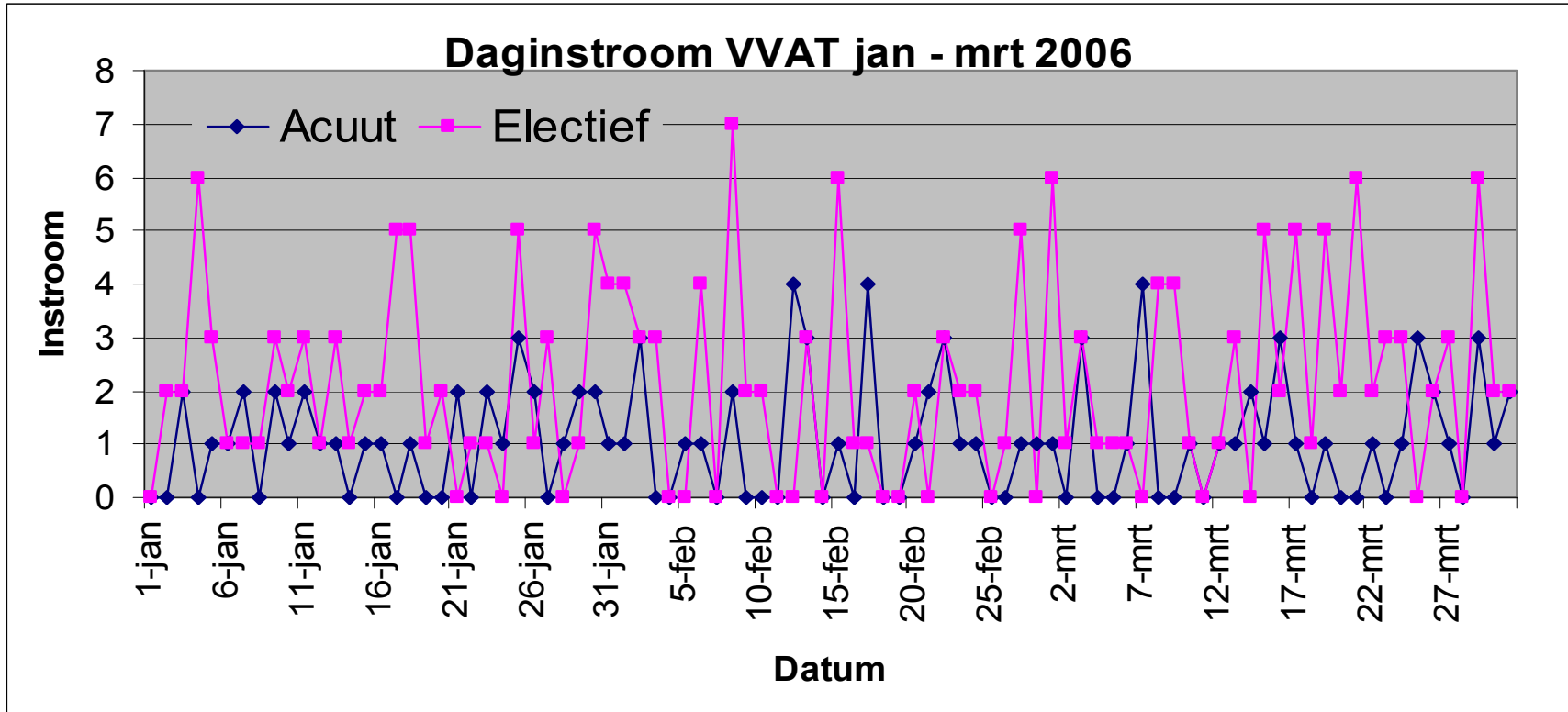
- Usual definition of utilization based on LoS measured in full days (for financial reasons)
- Consequence: Utilization can be  $>100\%$
- No correspondence to Erlang B



# Relation definitions

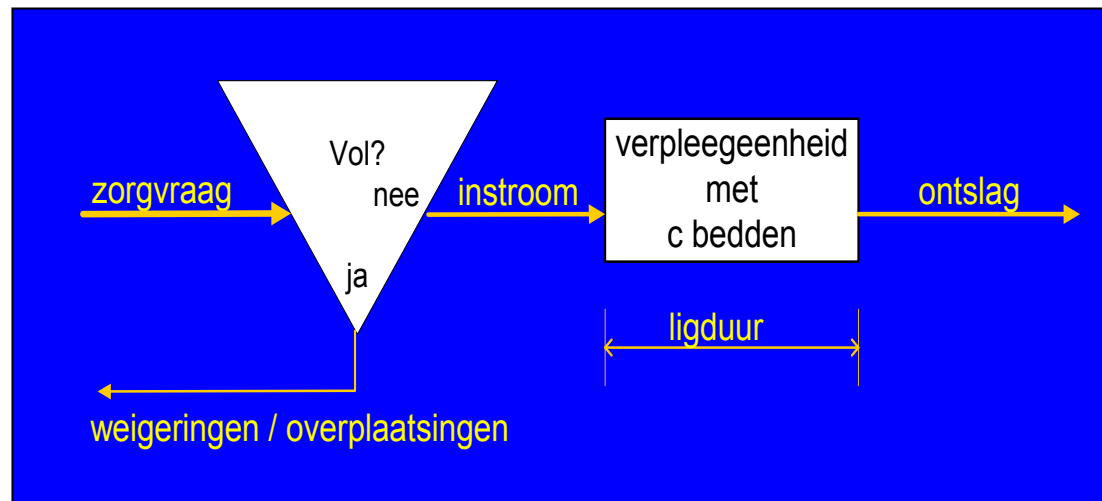
- Financial LoS = 1 + “real” LoS if
  - Arrival moment arbitrary = uniform over day
  - LoS exponential
- Then: Financial occupancy =  
Av No Arr / No beds + “real” occupancy
- But: not validated
- Thus: two parallel definitions

# Arrival process



# Analysis arrival data

- Arrival process not homogeneous Poisson (2<sup>nd</sup> half of the talk)
- Offered load is not measured!



# Results

- Discussion about required occupancy
- Scale matters (but merging should be done smartly!)
- Validation ok, but not excellent
- Questions about validity Poisson assumption
- Excel tool

**Rekenmodel voor klinische afdelingen**

invoer uitvoer huidige waarden

**Met deze tool kan...**

1. Het aantal benodigde bedden bepaald worden voor een bepaalde weigeringskans
2. De bedrijfsmatige bedbezetting en de bedbezetting volgens ziekenhuizen berekend worden  
De bedrijfsmatige bedbezetting is o.b.v. de werkelijke tijd dat patiënten aanwezig zijn in het ziekenhuis  
De bedbezetting die men binnen het ziekenhuis hanteert is o.b.v. verpleegdagen
3. De zorgvraag en het weigeringspercentage geschat worden
4. Het effect van afdelingen samenvoegen worden onderzocht

**STAP 1: Gegevens invoeren**

Hoeveel afdelingen wilt u bekijken/samenvoegen?  Bevestig aantal afdelingen

Voer het aantal in en klik op Bevestig aantal afdelingen

Klik vervolgens op Afdeling en kies voor een afdeling om de waarden van 2006 te importeren of kies voor zelf invullen en vul zelf waarden in de kolom in

|  | Totalen | Afdeling      |
|--|---------|---------------|
| Aantal verpleegdagen                     | 0       | Ve lon        |
| Tijd patiënten aanwezig (aanwezige uren) | 0       | Ve nch/ort    |
| Aantal operationele bedden               | 0,0     | Ve obs        |
| Aantal opnamen                           | 0       | Ve ori        |
| Aantal overplaatsingen                   | 0       | Ve oog        |
| Aantal dagbehandelingen                  | 0       | Ve val/nc     |
| Aantal pre-operatieve opnamen            | 0       | Ve vneu       |
| Aantal standaard bedden                  | 0,0     | Zelf invullen |

Klik vervolgens op Bevestig invoer

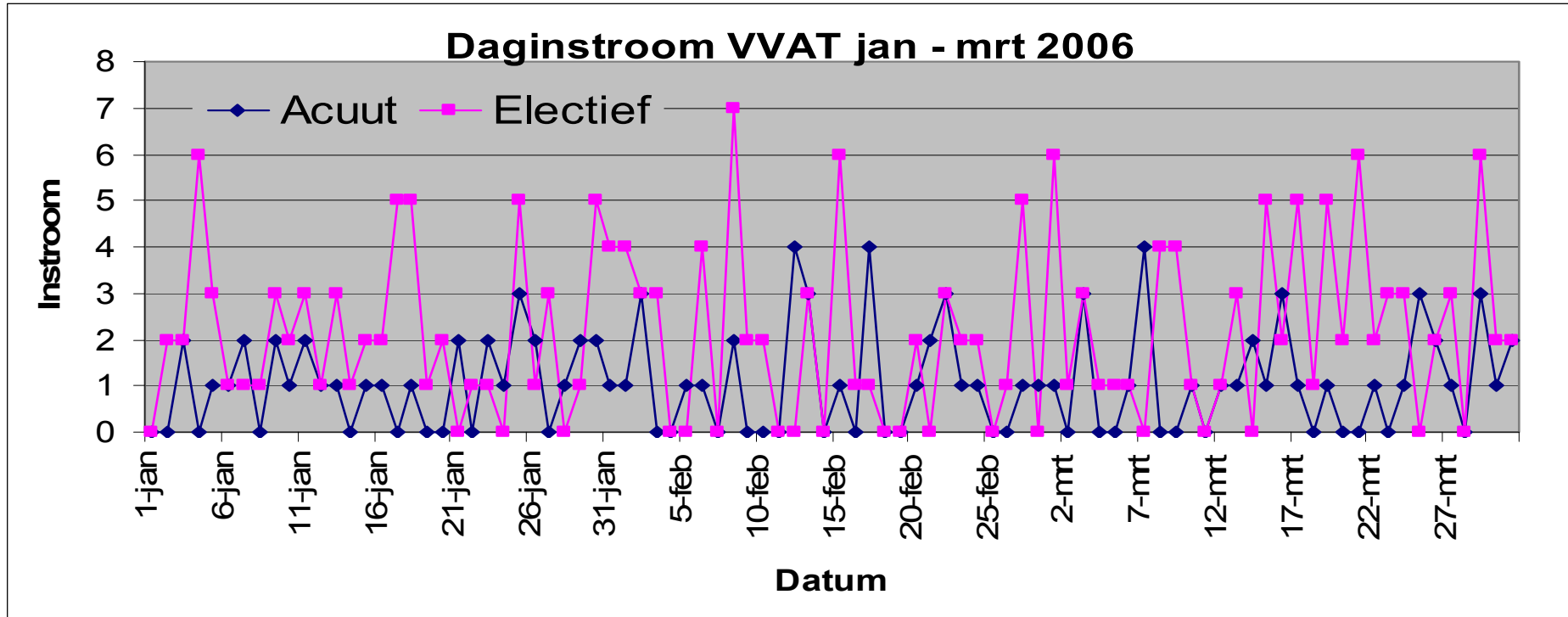
Totale instroom (inn + overol + dhh's + nre-over - nnn)

Programma / Gegevens2005 / Gegevens2006

# Arrival process

- Fact: arrival process  $\neq$  homogeneous Poisson process
  - Arrival rate fluctuates (day/night, weekday/weekend)
  - If at all Poisson! (elective surgery should be close to deterministic?)
- Next question (elective patients): what is the arrival process that we want?

# Elective vs. emergency

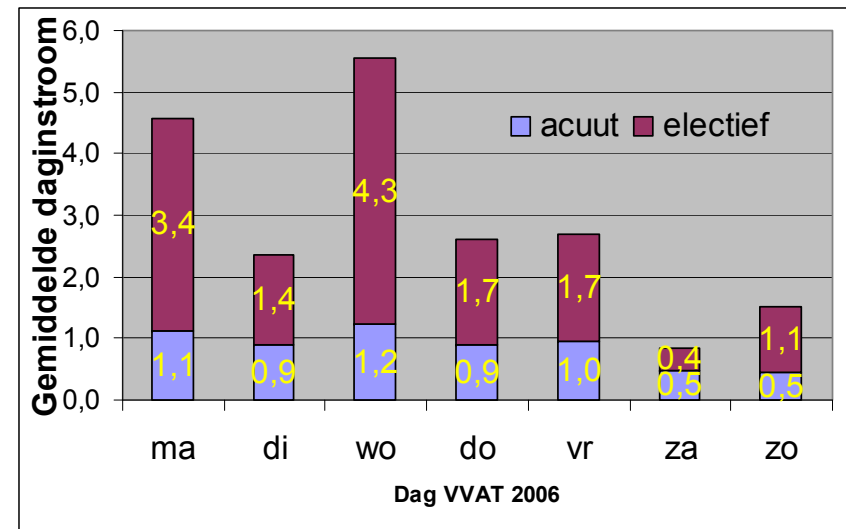


- Elective as variable as emergency!

# The elective arrival process

Elective arrivals to ward fluctuate because of:

- Operative schedule (e.g., 3 hips on We, none on Th)
- Deviations from operative schedule (e.g., cancelled operations)
- No elective operations in weekend

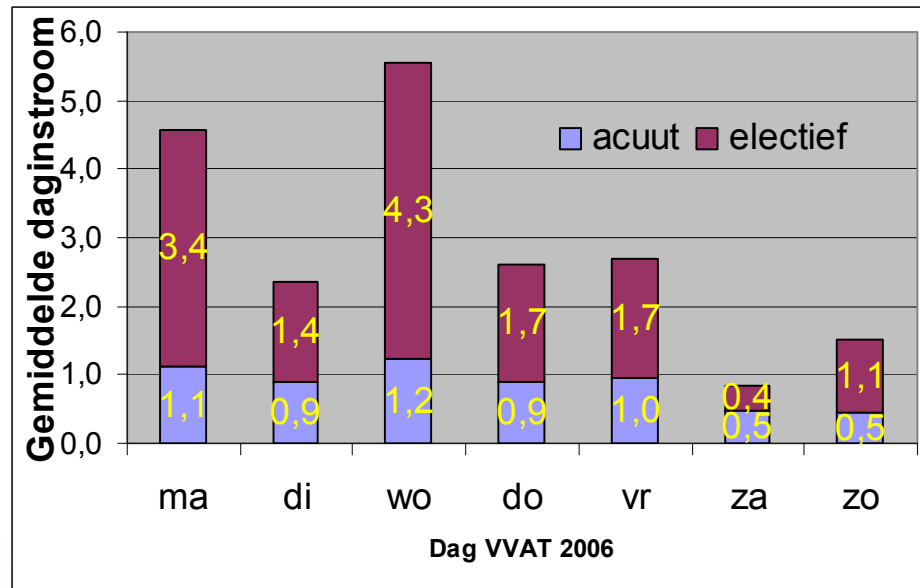


# Planning the elective process

- The more regular the arrival process → the more regular the demand → the better the performance
- Erlang B cannot be used anymore (use simulation)
- LoS distribution matters!

# Emergency arrivals

- Inhomogeneous Poisson process
- Rate fluctuates over the day
- Rate fluctuates over the week

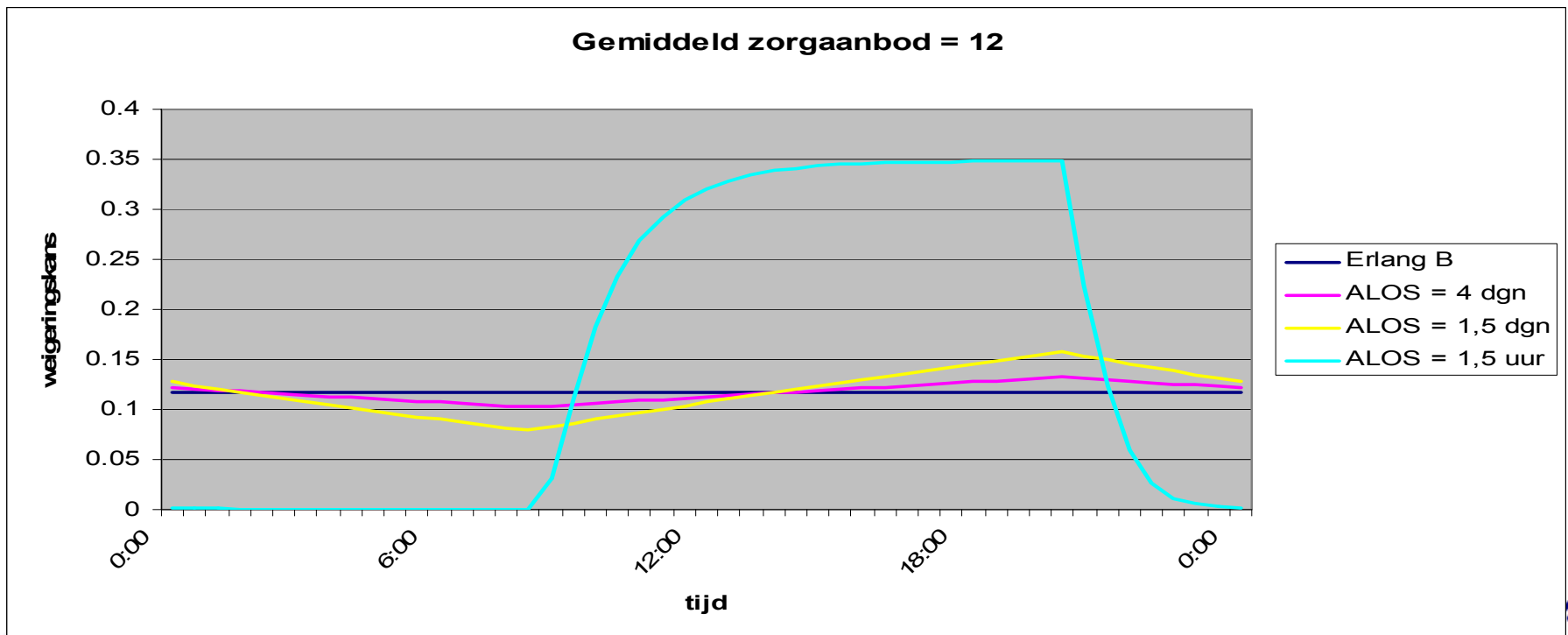


# Fluctuations in arrivals

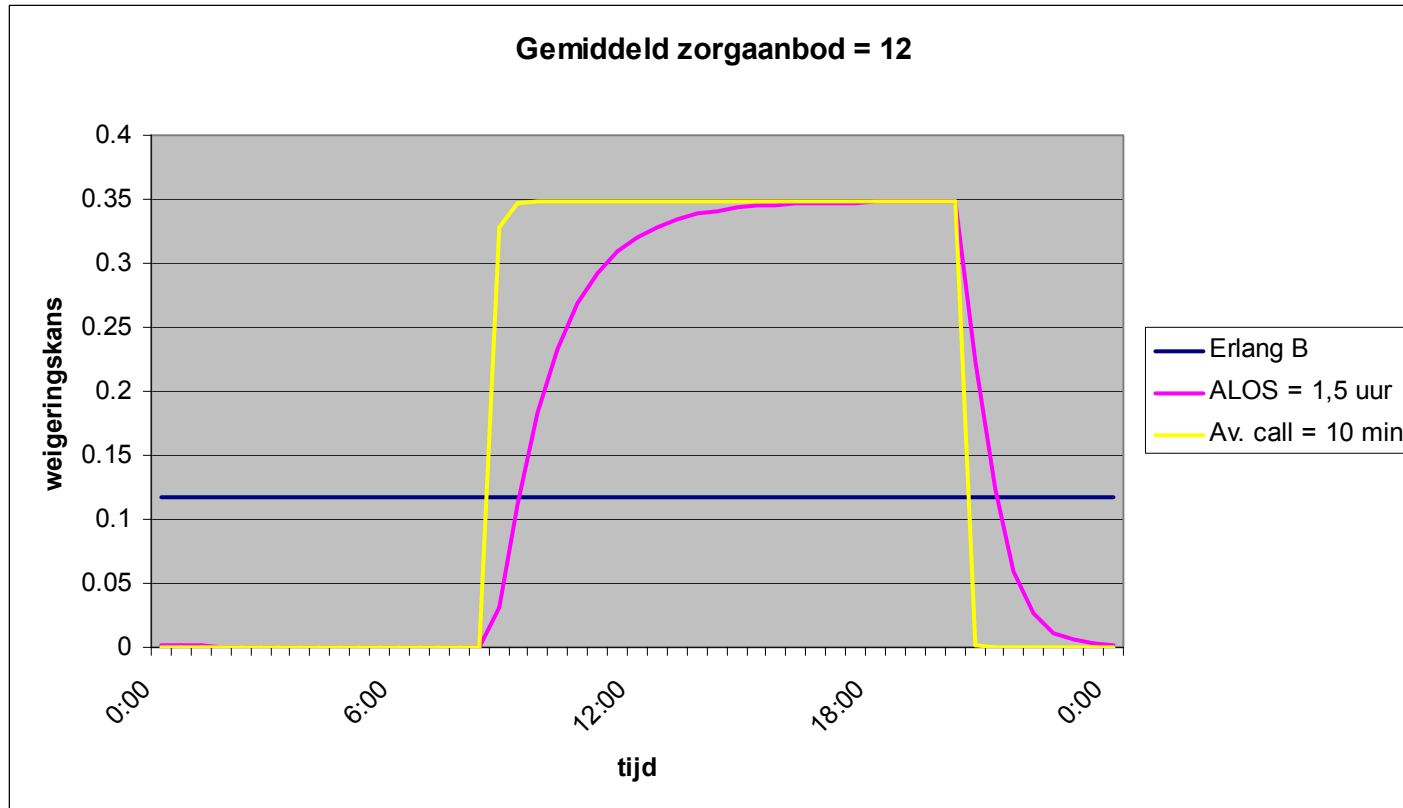
- What needs to be modeled depends on LoS. E.g.:
  - ICU, LoS multiple days, daily fluctuations less relevant
  - ED, stay multiple hours, daily rhythm crucial
- Compare with call center:  $ALoS = Av$   
handling time = several minutes
  - Erlang B/C for every interval (“Point by Point Stationary”)

# Example daily fluctuations

- Load = 12, 14 beds, arrival rates:
  - 0.20 per hour 8:00 – 20:00
  - 0.05 per hour 20:00 – 8:00



# Comparison call center



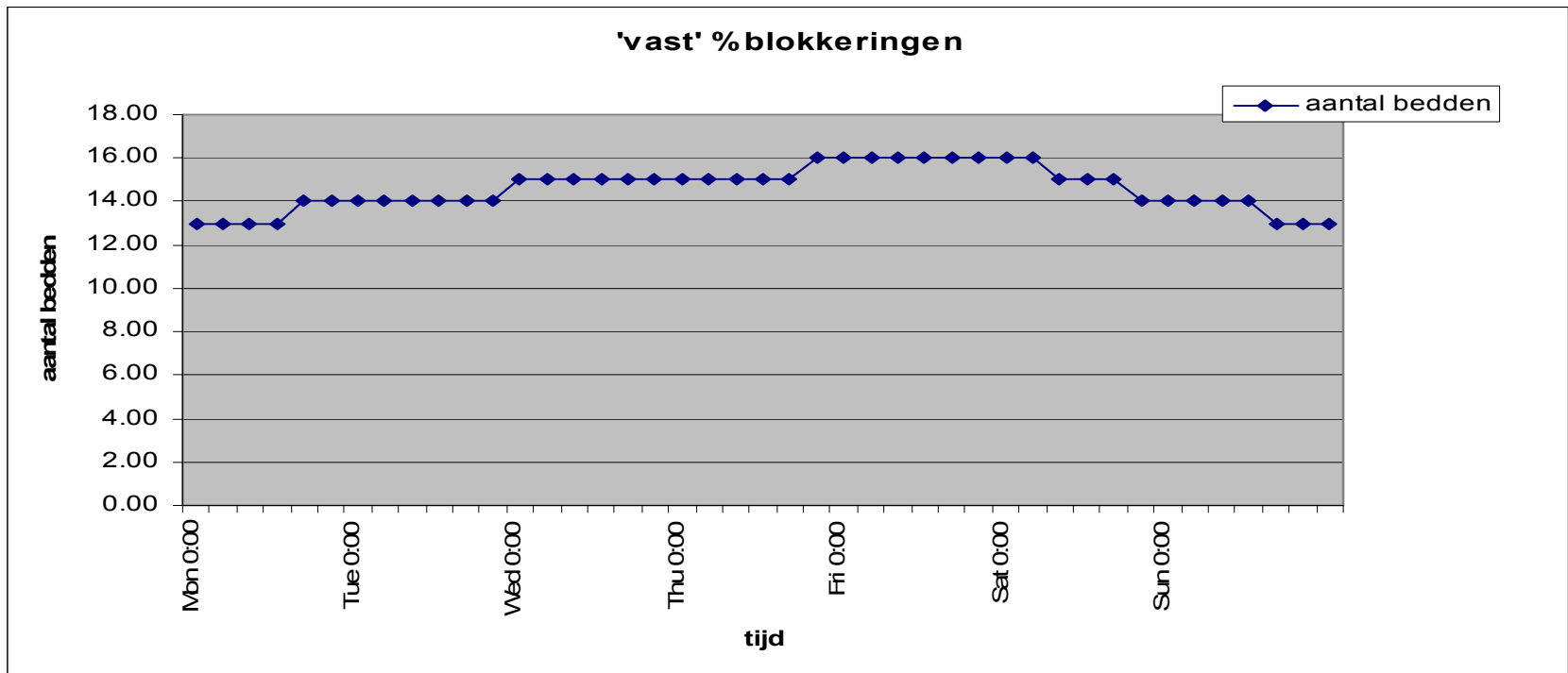
- A call center adapts its service capacity to the load

# Conclusions daily fluctuations

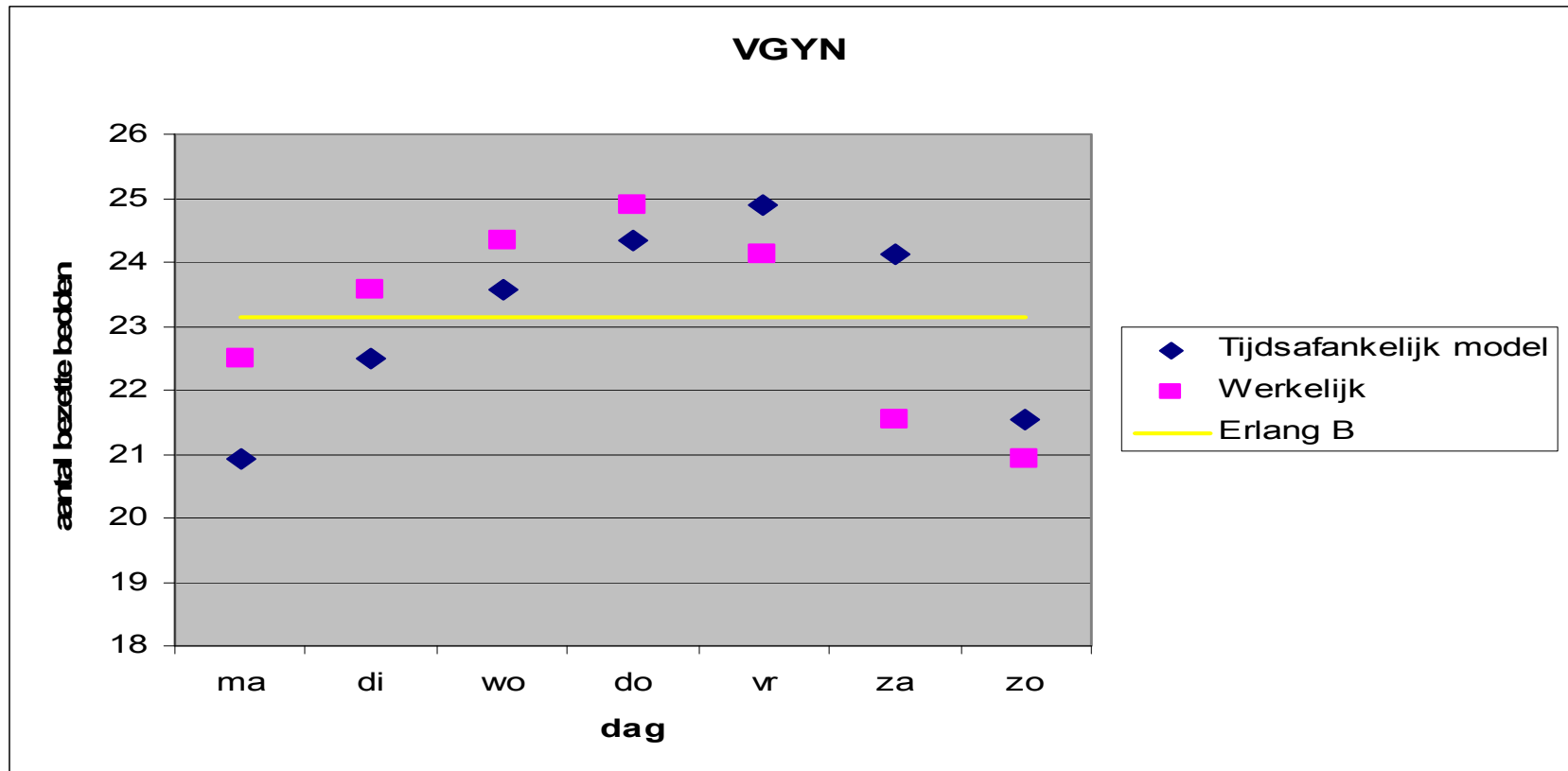
- Limited influence clinical wards (high ALoS)
- Relevant to ED
  - For ED simple transient model can be made

# Weekend effect

- Required no of beds for constant rejection prob.
- Simulation /  $\infty$ -server approximation



# Validation weekend effect

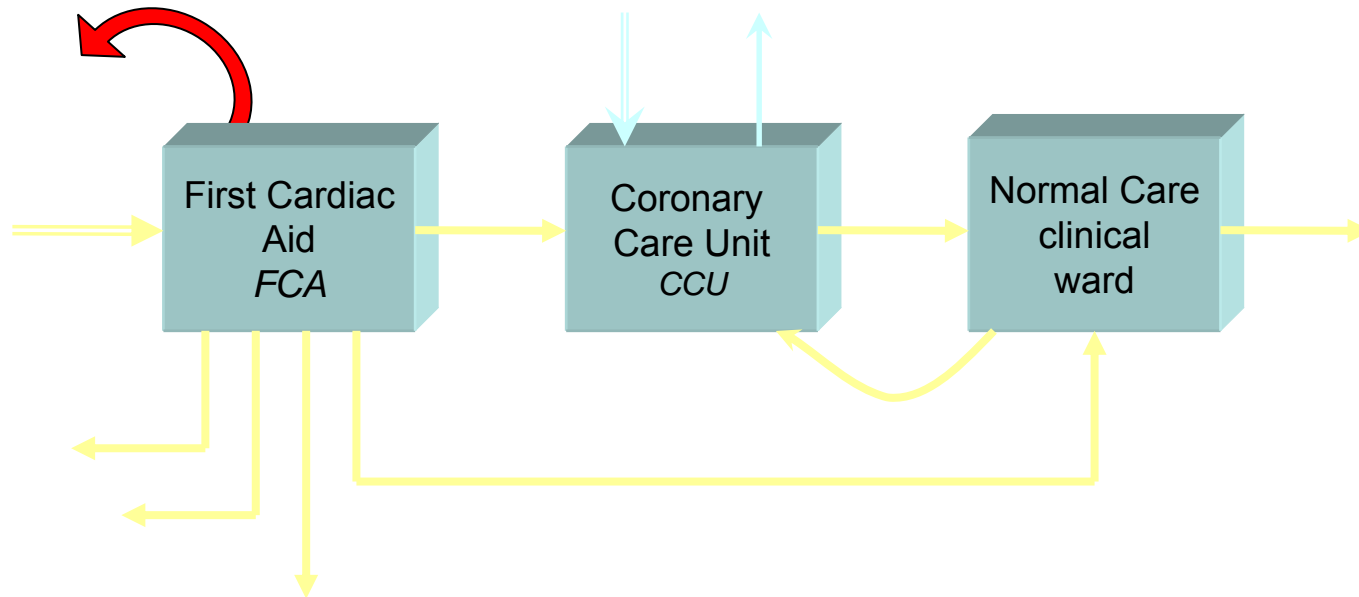


# Conclusions système de base 2

- Erlang B is a reasonable model for clinical wards
- Model can be improved by including weekly fluctuations
- Performance can be improved by reducing fluctuations elective process
- For ED daily fluctuations should be modeled

# Systeme de base 5: Chaînes de ressources

Travail commun avec Arnoud de Bruin MsC et Marieke Visser MD PhD

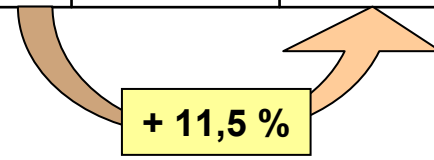


# Problem definition

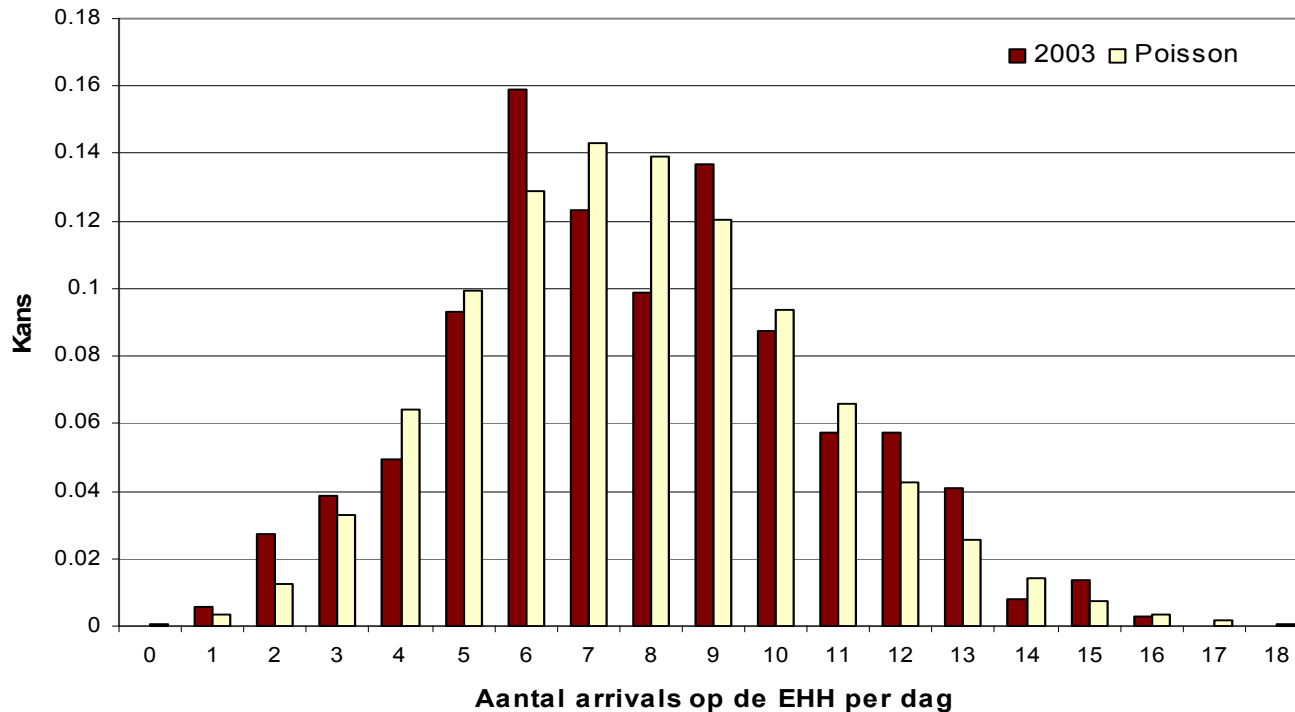
- Approximately 90% of cardiac in-patient flow is emergent and therefore hard to control
- Unacceptable number of refused admissions
  - 2002: 14%
  - 2003: 14%
  - 2004: 13%
- Goal: refused admission  $< 5\%$
- Analysis: where to add capacity?

# Key facts: flow par's from FCA

| Referral to:                   | 2003        | %           | 2004        | %           |
|--------------------------------|-------------|-------------|-------------|-------------|
| Home                           | 1899        | 66,9%       | 2229        | 70,4%       |
| Refused admission              | 383         | 13,5%       | 415         | 13,1%       |
| Coronary Care Unit (CCU)       | 314         | 11,1%       | 284         | 9,0%        |
| Normal care clinical ward (NC) | 128         | 4,5%        | 115         | 3,6%        |
| Other nursing unit             | 104         | 3,7%        | 100         | 3,2%        |
| Rest                           | 10          | 0,4%        | 21          | 0,7%        |
| <b>Totaal</b>                  | <b>2838</b> | <b>100%</b> | <b>3164</b> | <b>100%</b> |

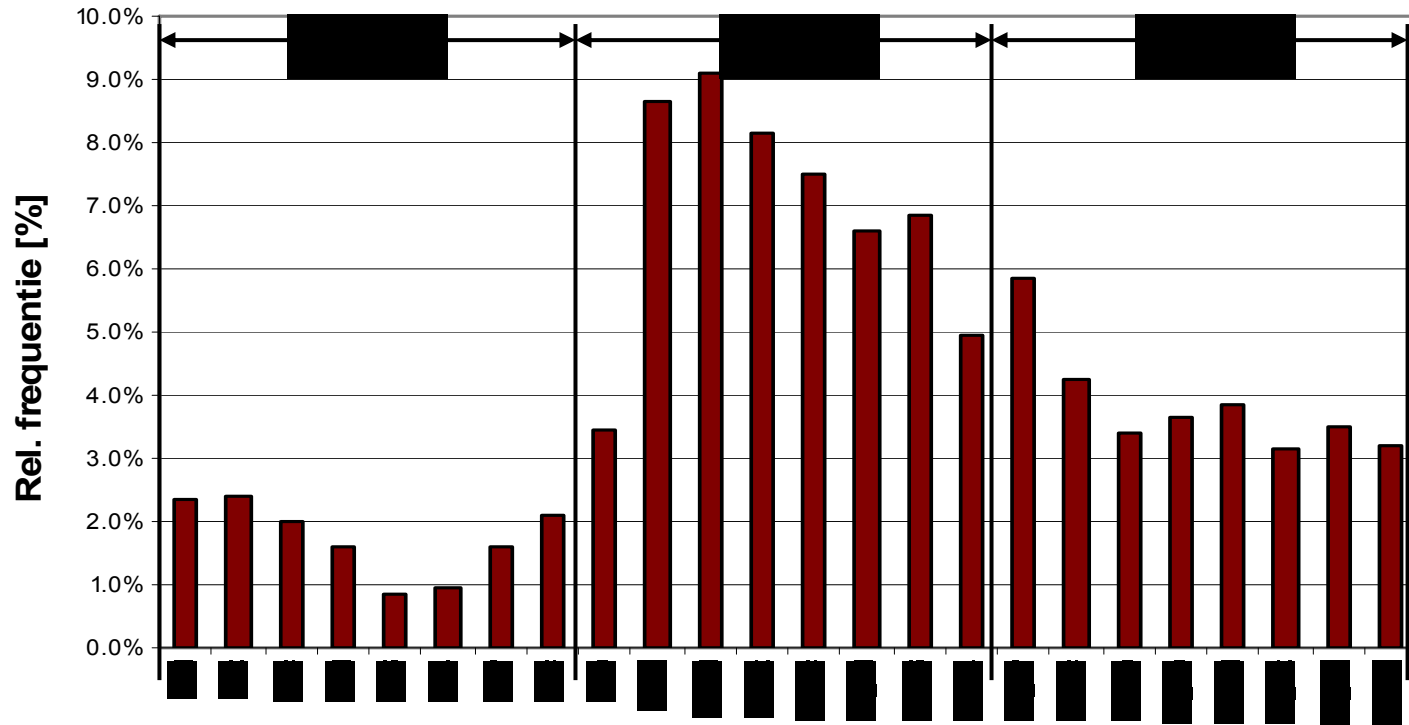


# Key facts: arrival process



Daily arrivals approximately Poisson

# Key facts: arrival process



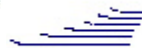
But: over day changing arrival rate

# Key facts: Lengths-of-Stay

- Average Length-Of-Stay FCA 6h, CCU 44h, NC 164h
- Coeff. of variation = standard dev / mean  $\approx$  1 for LOS CCU and NC
- Exponential dist LOS reasonable modeling assumption CCU and NC

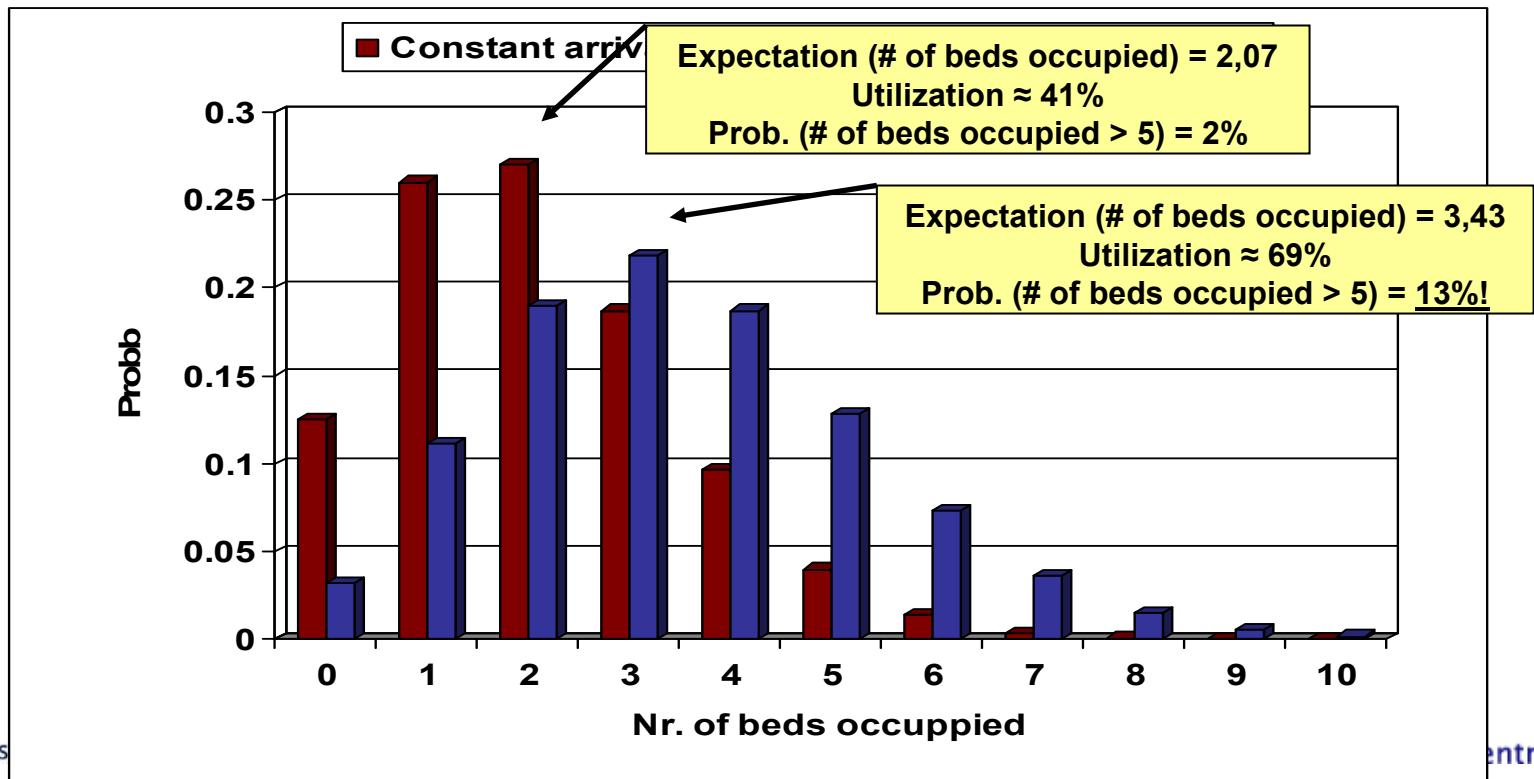
# Modeling choices

- Separate models for FCA and CCU/NCU
- Transient model for FCA taking into account arrival rate fluctuations and LOS distribution
  - Motivation: short LOS thus arr rate matters
- Stationary 2-dim queueing model for CCU/NCU with exp LOS
  - Motivation: coeff of var = 1
  - Long LOS, daily dist matters = Poisson
  - CCU bed is flexible, NC can start at CCU



# FCA: transient model

- $M_t / G / \infty$  model
- Dist at any time Poisson (with time-varying average)



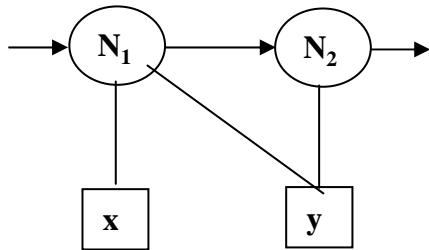
# FCA: transient model

- Constant arrival rate: 2% in excess of capacity
- Fluctuating (real) arrival rate: on average 4% in excess of capacity, 6% at peak hour
- Conclusion FCA: fluctuations arrival rate (and thus also dist LOS) crucial for accurate analysis

# CCU/NCU: stationary model

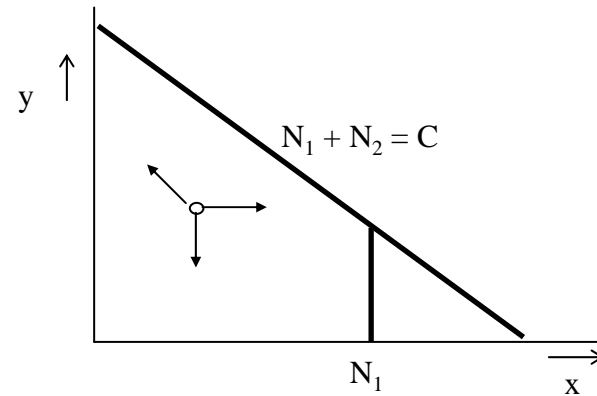
- NC can start at CCU (if NCU full)
- CCU bed twice as expensive as NC bed
- What is the optimal configuration?
- Common belief: avoid NC patients at CCU by having enough capacity at NCU
- Analysis: 2-dim MC allowing NC patients at CCU

# CCU/NCU: Markov chain model



$N_1$  = nr. of beds at CCU  
 $N_2$  = nr. of beds at NC  
 $x$  = nr. of CCU-patients  
 $y$  = nr. of NC-patients

$$\begin{aligned}x + y &\leq N_1 + N_2 \\x &\leq N_1\end{aligned}$$



# Model CCU/NCU: blocking %

| NC bd  | 12                  | 13   | 14   | 15   | 16   | 17   | 18   | 19   |
|--------|---------------------|------|------|------|------|------|------|------|
| CCU bd |                     |      |      |      |      |      |      |      |
| 5      | 27,8                | 24,3 | 23,9 | 23,7 | 23,6 | 23,6 | 23,6 | 23,6 |
| 6      | Blocking % too high |      |      | 15,7 | 15,2 | 15,0 | 14,9 | 14,9 |
| 7      | 15,7                | 10,8 | 9,9  | 9,20 | 8,77 | 8,77 | 8,77 | 8,77 |
| 8      | 12                  | 9,9  | 8,3  | 7,1  | 5,09 | 4,82 | 4,82 | 4,82 |
| 9      | 9,1                 | 7,2  | 5,8  | 3,15 | 2,75 | 2,49 | 2,49 | 2,49 |
| 10     | 6,85                | 5,04 | 2,3  | 1,77 | 1,44 | 1,23 | 1,23 | 1,23 |
| 11     | 5,5                 | 2,7  | 1,9  | 1,4  | 0,99 | 0,74 | 0,58 | 0,58 |
| 12     | 4,34                | 2,6  | 1,8  | 1,23 | 0,88 | 0,27 | 0,27 | 0,27 |
| 13     | 2,55                | 1,75 | 1,2  | 0,88 | 0,13 | 0,13 | 0,13 | 0,13 |
| 14     | 1,74                | 1,15 | 0,7  | 0,5  | 0,17 | 0,1  | 0,06 | 0,06 |
| 15     | 1,15                | 0,74 | 0,5  | 0,3  | 0,16 | 0,09 | 0,05 | 0,03 |

Blocking % too high

Solution area

Blocking % "too" low

# Model CCU/NCU: costs

| NC bd  | 12   | 13    | 14   | 15    | 16   | 17    | 18   | 19    |
|--------|------|-------|------|-------|------|-------|------|-------|
| CCU bd |      |       |      |       |      |       |      |       |
| 5      | 22,4 | 23,35 | 24,3 | 25,25 | 26,2 | 27,15 | 28,1 | 29,05 |
| 6      | 24,6 | 25,55 | 26,5 | 27,45 | 28,4 | 29,35 | 30,3 | 31,25 |
| 7      | 26,8 | 27,75 | 28,7 | 29,65 | 30,6 | 31,55 | 32,5 | 33,45 |
| 8      | 29   | 29,95 | 30,9 | 31,85 | 32,8 | 33,75 | 34,7 | 35,6  |
| 9      | 31,2 | 32,15 | 33,1 | 34,0  | 35,0 | 35,9  | 36,9 | 37,85 |
| 10     | 33,4 | 34,35 | 35,3 | 36,25 | 37,2 | 38,15 | 39,1 | 40,05 |
| 11     | 35,6 | 36,5  | 37,5 | 38,45 | 39,4 | 40,35 | 41,3 | 42,25 |
| 12     | 37,8 | 38,75 | 39,7 | 40,65 | 41,6 | 42,55 | 43,5 | 44,45 |
| 13     | 40   | 40,95 | 41,9 | 42,85 | 43,8 | 44,75 | 45,7 | 46,65 |
| 14     | 42,2 | 43,15 | 44,1 | 45,05 | 46   | 46,95 | 47,9 | 48,85 |
| 15     | 44,4 | 45,35 | 46,3 | 47,25 | 48,2 | 49,15 | 50,1 | 51,05 |

OPTIMUM



# Conclusions système de base 5

- Investing in flexible and expensive CCU beds can also be cost-effective
- Thus sometimes NC patients in CCU beds
- Other solutions outside scope study:  
flexible pooling & prioritizing NC beds  
between specialisms

# Publications

- Serveur unique, patients consecutives : HCMS 07
- Dimensionnement et allocation de ressources des serveurs parallèles : soumis
- Ressources partagées : recherche avec Paulien Out
- Prise de ressources simultane : sujet de recherche
- Chaîne de ressources: HCMS 07

# PICA

- PICA: Patientflow Improvement Center Amsterdam
- Cooperation between theory and practice
- Managers, doctors and quants involved
- Weekly seminar at VUmc: [pica@vumc.nl](mailto:pica@vumc.nl)
- [www.vumc.nl/PICA](http://www.vumc.nl/PICA)